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THE

JOURNAL OF GEOLOGY

APRIL-MAY, 1894.

THE OIL SHALES OF THE SCOTTISH CARBONIFEROUS SYSTEM.

THE Lower Carboniferous Rocks of the east of Scotland have within the last quarter of a century attained great economic and geological interest from the oil-bearing shales they have been found to contain. The district around Edinburgh is one of great complication, and until the operations of the shale mines began large parts of the ground which is usually deeply covered with glacial drift were geologically but imperfectly explored. It is only recently that the chief oil shale districts have been mapped correctly, and the new edition of the geological map of the Edinburgh district, on which I have been engaged for several years tracing out the oil shale outcrops, etc., has only been published within the last six months. A detailed account of the structure of this area has not yet been published, and beyond a few short papers by myself and others in various scientific journals, nothing of importance has been written on this interesting subject.

The Carboniferous system of Scotland is broadly divisible into the following groups:

4. Coal Measures, with the most important coals.

3. Millstone grit, chiefly barren sandstones.

2. Carboniferous Limestone Series, with beds of limestone above and below, and shales, sandstones, etc., interbedded with seams of excellent coal in the center.

1. Calciferous Sandstone Series, with sandstones, estuarine limestones, marls, seams of oil shale and occasional impure coal, the *base of the series consisting of coarse red sandstones, shales and marls resting on the Old Red Sandstone.*

The oil shales of Scotland are confined almost exclusively to the "Calciferous sandstone" strata in the Edinburgh district, and the principal seams occur in West Lothian, where the most important oil works are situated, about twelve miles west of the Scottish metropolis.

Broadly speaking, Edinburgh is situated on a great anticline, in the center of which there rises a ridge of Silurian and Old Red Sandstone rocks, partly igneous and partly sedimentary, whose general strike is northeast and southwest. The hard volcanic strata and igneous intrusions in these older rocks have produced most of the pictureqe ranges of hills in the vicinity of Edinburgh, and the softer beds in the higher parts of the series dip away, with many complications, from either side of the central axis. To the east of the Pentland ridge the inclination of the beds is very high, and comparatively regular, and consequently the whole thickness of the calciferous sandstone series can be traversed in a short time. There is also here a large fault running along the base of the hills which conceals the lowest of the calciferous series of rocks and brings up the old volcanic beds against the upper parts of the oil-bearing strata, and indeed at one place the dislocation has been so great that the calciferous rocks with their oil shales are almost entirely hidden, and the upper beds of the Old Red Sandstone abut almost directly on the base of the marine limestone series.

The Carboniferous limestones along this line, with their interbedded coal seams, are inclined for long distances at the same high angle and plunge at places almost vertically downwards beneath the long and regular trough of Dalkeith Coal Measures, from which they emerge five or six miles farther east at a much lower inclination.

To the west of the Edinburgh anticlinal the structure of the district is much more complicated. The Calciferous rocks spread out for fifteen or sixteen miles in a tumultuous sea of undulations, basins and folds cut up by multitudes of faults, and traversed by numerous necks, sheets and dykes of intrusive igneous rock, to map which, even with the aid of copious mining information, is often a task of the greatest difficulty. The rapid thinning and thickening of some of the members of the series also adds an element of difficulty to the elucidation of the structure of the district, and although many hundreds and even thousands of borings have been made in search of oil shale and other rocks, there are places where, in the absence of surface exposures, the structure of the area has still to be ascertained.

The total thickness of the Carboniferous Limestone series of Mid and West Lothian is about 2,000 feet, and that of the upper or oil shale division of the underlying calciferous series is a little over 3,000 feet. Beneath the oil shale series there is a group of shales, fire clays and gray sandstones, one of which, formerly quarried very extensively at Craigleith, supplied nearly all the celebrated freestone from which a large part of the New Town of Edinburgh was built. Owing to its great hardness and cost of working the Craigleith stone has now been nearly given up and is only used where great strength is wanted in house architecture, or for export to America, where it appears to be used occasionally for special work. This middle division of the Calciferous Sandstone series appears to be about 3,000 feet thick, and the red beds which lie below cannot be much thinner, so that 9,000 feet may be taken as the approximate distance from the top of the Old Red Sandstone to the highest part of the Oil shale series in this locality.

Dealing now in greater detail with the Oil shale group of rocks, it may be noted, first, that the whole series has a fresh water or estuarine character, and contains few or no strata of a marine type. There are numerous thin bands of concretionary unfossiliferous limestone, and one well-marked bed of richly fossiliferous estuarine limestone of workable thickness. This rock—the Burdiehouse Limestone—in addition to fresh water shells, contains fish plates, teeth, etc., and many plant remains such as *lepidodendron* and *sphenopteris*, and is at places directly covered by a bed of black bituminous shale of inferior oil-producing quality. The series is also characterized by numerous well-marked beds of unfossilferous red, green and gray marl, the origin of which is not very clear, but as the marl is seen at places to contain pieces of felspathic volcanic ash, it seems reasonable to suppose that it may be made up in part at least of impalpable mud derived either from volcanic dust or from the disintegration of some old volcanic area which has now disappeared from view, but which formed part of the ancient mainland from which the other sediments were derived. There is no distinct evidence of volcanic action during the greater part of the Oil shale period in the Lothians, and the numerous ash necks which pierce the strata were probably connected with the extensive outbursts which took place during the subsequent Carboniferous Limestone period. Many beds of gray and yellow sandstone are found interbedded with the oil shales as well as impure coals, fire clays, and non-bituminous carbonaceous shales —the "blaes" of the Scottish mines, in which plant remains, and fresh-water molluscan forms are at places found in abundance.

The Scottish Oil shales are simply beds of very fine impalpable clay shale highly impregnated with hydrocarbon, easily distinguished in the field by their resistance to the disintegrating action of the weather, thin brown streak, and the facility with which they can be cut and curled up with a sharp knife. The texture is at times tough, almost leathery, and thin pieces are slightly flexible and easily distinguishable from ordinary black carbonaceous "blaes" with which they are often closely associated. When lit with a match oil shale burns, as a rule, brightly, leaving a finely laminated skeleton of ash after all the hydrocarbon has been exhausted. On distillation the yield of oil varies. Good shales should give, per ton, at least thirty gallons of crude petroleum, as well as enough ammonia to produce, when neutralized with sulphuric acid, from ten to fifty pounds of sulphate of ammonia. This product is often as valuable as the oil, and much skill has been employed in the construction of retorts to extract it completely. The crude oil when refined gives various products, such as tar, naphtha, paraffin, light illuminating and heavy lubricating oils, and the oil industry of the Lothians was for more than a quarter of a century a source of great profit and employment to the capitalists and operatives of the district, but of late years the severe competition with foreign producers has made most of the works quite unremunerative. The thickness of the oil shale beds varies considerably from place to place, and it is quite common to find a good seam thinning out in one district and passing into ordinary carbonaceous shale, or disappearing altogether, while another seam above or below it may improve in quality in proportion as the first deteriorates. The Broxburn shale—the richest seam in the Broxburn district —varies in thickness from about two and a half to eight feet, and the Dunnet shale reaches at places a workable thickness of thirteen feet.

An interesting phenomenon is observable at some places where the strata have been heated by igneous intrusions. In these cases if an oil shale bed has been affected by the heat, partial distillation has followed, and the surrounding rocks, including the eruptive sheet itself, have become impregnated with the hydrocarbonaceous ingredients expelled from the shales. In a recent diamond boring a core of the eruptive dolerite was brought up from a depth of over 600 feet, traversed by veins of solid paraffin, which melted when the rock was laid in the sun, and at the outcrop of this intrusive sheet it is found to contain cavities filled with tarry matter and to give off a strong bituminous odor when freshly broken with the hammer. This eruptive sheet has forced its way for miles through strata adjoining the Broxburn shale, and whenever it has touched or even approached the shale the seam has of course become quite worthless economically. The well-known sandstone of Binney, which is located some fathoms below the Broxburn shale, has long been known to contain veins of ozocerite or an allied hydrocarbon, and the quarrymen used formerly, when the rock was extensively worked for building and monumental purposes, to make black candles of the substance, some of which are still preserved in the Science and Art Museum in Edinburgh. There can be little doubt that this "mineral" owes its origin to the distillation of the bituminous matters by the igneous intrusions in the vicinity of the overlying oil shale.

The oil shales occur within an area roughly twenty miles in diameter. On the north shore of the Firth of Forth only one seam of workable quality is known, and all the others have apparently disappeared and become replaced by more arenaceous rocks, while in the Lower Carboniferous deposits in other parts of Scotland no oil shales of any value have been yet discovered. These valuable deposits appear to have been found in broad lagoons into which vegetable matter was brought in a very fine state of division, and laid down along with a small quantity of inorganic silt under conditions of great tranquillity. That the hydrocarbon is however sometimes of animal origin is clear from the quantity of cyprids that make up some of the shales. Large plant remains are rare, but beautifully preserved fronds of *sphenopteris affinis*, and other ferns are abundant in some of the beds of oil shale. There cannot have been currents of any strength sweeping through the lakes of the Scottish oil-shale period, otherwise the light organic particles would have been at once swept away, and this order of things must, with periodical interruptions, have obtained within the shale region for a long succession of ages, during which deposits accumulated to a depth of over 3,000 feet.

Liquid petroleum has been occasionally found exuding in small quantities from the joints of these sedimentary rocks, and there is at St. Catherines, about three miles south of Edinburgh, a spring situated on the line of the great fault east of the Pentland axis already referred to, known for many centuries as the Balm Well, whose surface is covered by a film of mineral oil derived no doubt from the slow distillation of the oil shales on the downthrow side of the dislocation. We cannot, however, boast of anything like the famous oil wells of Pennsylvania, which I had the pleasure of visiting in 1891, and even were there rich oil sands among the Califerious sandstones of the

Scottish Lothians, the exceeding faulted and disturbed nature of the Carboniferous system in this locality would effectually prevent the circulation underground of any quantity of fluid hydrocarbons except within extremely limited areas.

The following is a general section of the oil shale series west of Edinburgh:

	FEET.
Strata below base of Carboniferous Limestone series about	400
Raeburns Shale, 3 to 4 feet strata,	190
Mungals Shale, about 1 ft. 9 ins. strata,	170
Coal and Gray cypride Shale 2 ft. "Houston Marl" group	200
Strata laminated sandstones,	240
Fells Shale, 3 to 5 feet, "Broxburn Marl" group, 80 to	270
Broxburn Shale 2½ to 8 feet, "Binney Sandstones" and strata,	450
Dunnet Shale, 6 to 13feet, strata chiefly shales, fire clays, etc.	400
Barracks Shale, resting on the estuarine Burdiehouse Limestone, 10 to 50 feet thick at places, strata about	780
Pumpherston Shales, about 6 feet worked.	
Apparent thickness of Oil shale series,	3,100

Henry M. Cadell.